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ASSESSMENT OF THE FACTORS AFFECTING ADVANCED LIFTING ENTRY VEHICLES

ALFRED C. DRAPER
MELVIN L. BUCK

TECHNICAL REPORT AFFDL-TR-67-137

JANUARY 1968

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ABSTRACT

Many investigations related to hypersonic flight and reentry have been conducted and from the results of these studies, design concepts have been evolved across the complete lift-to-drag ratio spectrum for entry. This report considers the relationship between any new lifting entry vehicle and the established low L/D or ballistic spacecraft technology. It is shown that a substantial base of knowledge exists from the successful flights of the ASSET and SV-5D along with the technology obtained from the X-20 program. To place lifting vehicles in their proper perspective, a review of some of the advantages traditionally associated with the generation of lift is given, and a realistic view is taken of some of the maneuvering constraints which can be required. Particular emphasis is placed on the performance flexibility which can be achieved. Specific technology features common to complementary advanced systems are identified and assessed relative to launch vehicle constraints. The evolution of highly efficient lifting bodies is traced. Potential configurations for reentry are delineated, and these configurations are assessed in relation to their heating, volume, and weight. The incorporation of man and on-board propulsion is shown to be completely compatible and advantageous with the candidate high L/D configurations. In conclusion the lack of well-defined mission requirements indicates the advisability of preserving the options available.

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MELVIN L. BUCK

FOREWORD

This report was prepared by the Flight Mechanics Division, Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. The work was accomplished under Project No. 1366, "Aerodynamics and Flight Mechanics." Alfred C. Draper and Melvin L. Buck were the project engineers. This report covers work conducted from November 1966 to April 1967. The manuscript was released by the authors in May 1967.

This technical report has been reviewed and is approved.

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SYMBOLS

C^*	Chapman-Rubsien constant
L/D	lift-to-drag ratio
M_∞	freestream Mach number
R_N	Reynolds number
T	temperature - °F
W/S	wing loading
ΔV	velocity increment - Fps
W	weight - Lbs
I_{sp}	specific impulse
C_{Lmax}	maximum lift coefficient
$W/C_L S$	equilibrium glide parameter
V	volume - Ft^3
V_i	ratio of velocity to orbital velocity
S	vehicle reference area - Ft^2
$S_{footprint}$	area of reentry footprint - $(NM)^2$
S_{earth}	area of earth's surface - $(NM)^2$
S_{wet}	vehicle wetted area - Ft^2
$\frac{V^{2/3}}{S_{wet}}$	volumetric efficiency
η_{GL}	delivery index
γ	reentry angle

SECTION I

INTRODUCTION

An often referenced article (Reference 1) discussing the prospects for a manned lifting entry research vehicle expressed hope that a future development program in this area would not suffer the fate of being reviewed into nonexistence. Although it is understandable that review at times may be feared particularly if it results in the demise of a favorite concept; nevertheless, the advantages associated with a penetrating and judicial review are believed to outweigh any undesirable features. This is true when viewed relative to the high costs which must be accrued both from vehicle and booster acquisition as well as ground support and data acquisition. The resource requirements demanded by vehicles, which necessitate sophisticated thermal protection systems and relatively large launch systems, makes consideration of alternate or competitive concepts not only desirable but mandatory. The necessity of selecting the most attractive option from many alternatives is, perhaps, more important today than in previous years, for our appreciation of realistic systems effectiveness criteria has admittedly matured.

Another factor that must be considered carefully is the relationship of any new lifting entry vehicle with established spacecraft technology. This point cannot be emphasized too strongly, for in a realistic appraisal of facts, the lifting entry enthusiast must acknowledge the existence of a proven competitive technology of ballistic and modified ballistic spacecraft. The outstanding success enjoyed by both the Mercury and Gemini spacecraft has established a record which presents a formidable challenge to any future concept. A logical extension of established technology is evidenced in the Apollo program, and we are confident that a high measure of success will result in its pursuance. More importantly, however, it is anticipated that the spacecraft will have the inherent capability of performing a variety of missions quite diverse from its lunar high energy reentry objectives. For example, it has been shown repeatedly that for the pure logistics mission, the minimum cost and spacecraft weight is achieved with the low L/D systems. In a similar manner, the satellite inspection missions requiring no urgency favor the low L/D systems from both the cost and ΔV considerations. Perhaps the only serious stated deficiency on the part of the low L/D spacecraft in performing the logistic's mission is its inability to perform a land-landing. This deficiency, of course, can be rectified by a number of devices currently being investigated which were formerly called auxiliary landing aides and now "decoupled modes." It also should be recognized that vehicle reliability now associated with vertical landings is quite high, and water landings must still be considered in view of abort contingencies. In view of these recognized advantages of size, weight, volume, cost, reliability, and simplicity associated with the low L/D spacecraft; it becomes clearly incumbent upon the proponent of any new spacecraft concept to demonstrate measureable and significant performance improvements. Unless meaningful and undebatable augmentations in performance can be achieved, the likelihood of any major resource allocations for advanced entry vehicles should be rightfully pessimistic.

In any assessment of advanced entry concepts, it is necessary to emphasize that a vacuum does not exist relative to the investigation of lifting vehicles. We must only recall the highly successful flights of the ASSET vehicles with a hypersonic L/D of approximately 1.4 and with the radiative thermal protection concept. This medium L/D technology was further enhanced with the flights of the SV-5 PRIME vehicle with an L/D $\approx$ 1.2 and with an ablative material for thermal protection. These latter flights when coupled with the midspeed tests of the manned SV-5P, M2F2, and HL-10 lifting bodies should certainly demonstrate our confidence in this class of vehicles.

Let us turn our attention to the question associated with the renewed interest in the L/D 2.0 vehicle. This in itself represents, for the most part, a compromise approach. The argument is made that the medium L/D vehicle is, when based on realistic mission considerations, delinquent in performance but that the L/D 3.0 concepts, although admittedly operationally versatile, probably taxes excessively the state of the art. A further point is made that very little attention has been focused on the L/D 2.0 class of configurations. This is really not the case. In a realistic analysis, it is only necessary to recall the large effort of a few years ago associated with the X-20 program, an L/D 2.0 vehicle. Rather it is more correct to state that with the funding levels reached in this program, the problems associated with the L/D 2.0 class of vehicle have had more effort expended on it than any other concept. The situation can be summarized by stating that if an L/D 2.0 configuration can, indeed, satisfy the operational requirements, then the technology for such a vehicle already exists. And, perhaps of equal importance, a configuration which has, from approximately 20,000 wind tunnel hours, been thoroughly verified as being trimmed, stable, and controllable throughout the entire Mach number spectrum. To debate whether the L/D should be 1.7 or 2.0 makes very little sense. There is very little difference in the configurations and both represent nearly the same technology demands. It seems logical to simply accept the latter to accommodate unknown performance contingencies.

The essence of the matter is that if a clearly defined requirement exists which can specify the maneuverability demands and hence L/D requirements, then the mission oriented vehicle should be selected and fabricated. If, however, these "requirements" are really not defined, then it would be wiser to accept the performance potential available along with the capability for technology acquistion with the largest possible applicability to advanced systems' concepts.

SECTION II

PERFORMANCE AND TECHNOLOGY

ADVANTAGES OF LIFT

Maneuverability with reentry vehicles normally suggests the use of lift in that the longitudinal range may be modulated and different degrees of lateral range may be achieved depending on the L/D. The use of propulsion, however, represents an option for achieving maneuverability which must be compared to aerodynamic lift; both of which impose some weight penalty. Figure 1 gives an indication of the weight associated with lift generation converted into a hypothetical fuel and I_{sp} for attaining complementary lateral ranges (Reference 2). It is obvious that vehicles with high aerodynamic efficiency are superior to advanced propulsion systems. This is further amplified in Figure 2 which shows the aerodynamic and propulsive trade-offs for equivalent L/D. Here we have normalized to a L/D 1.5 and have indicated the weight growth necessary for increased lateral range as a function of I_{sp} and aerodynamic design.

MANEUVERING CONSTRAINTS

Another area which warrants more careful consideration is that of realistic maneuvering design goals, for it seems that the general tendency can best be characterized as a "design down" philosophy. The argument being simply that for certain idealized missions we may or may not need significant maneuverability; we may or may not desire improved return times; we may or may not be content with bases located both within and without the zone of the interior; and we may or may not desire a capability for contingencies and mission versatility. This appears to be a questionable design logic. It would appear prudent to achieve a capability if indeed there existed certain applications and contingency requirements which could realistically take advantage of such potential. This decision, of course, must carefully consider not only the technological state of the art, but also assess and minimize any penalties which might be associated with increased performance potential relative to the maneuverability desired. For example, Reference 1 on the same subject after briefly discussing return requirements as a function of orbit inclination rapidly converged the discussion with the conclusions that the orbit of most immediate interest is 30 degrees, that we had a world wide availability of landing sites and hence an L/D 1.0 class of vehicle is adequate. This, we would suggest, may not represent at all a realistic appraisal of the situation. Rather the facts of the matter from the viewpoint of military application may be a requirement of returning quite rapidly from random orbits. In Figure 3 we find that for L/D's of less than 3.0, bases outside the zone of the interior of the U. S. are required to recover the vehicle. The number of bases increase rapidly for L/D's less than 2; and for an L/D of 1.0, it would be impossible to provide sufficient bases. Let us make it clear that never have we advocated the so called "lone base" concept which incidently demands an L/D of approximately 4.0 but have confined our activities to an L/D of 3.0 to assure U. S. recovery at secure bases. Further we would suggest that the orbits "of most immediate interest" may be those more highly inclined as achieved from the Western Test Range. Figure 4 shows the maximum lateral range requirements for return to Edwards after single and multiorbits at various launch azimuths within existing range constraints. The lateral range requirements for the single and dual passes are 1250 and 2350 NM respectively without accounting for guidance and control errors, density variations, etc., which, of course, would further escalate the lateral requirements. We have superimposed on the figure the capability of the L/D 1.0 class of vehicle and can readily state that return would be impossible for most launch azimuths.

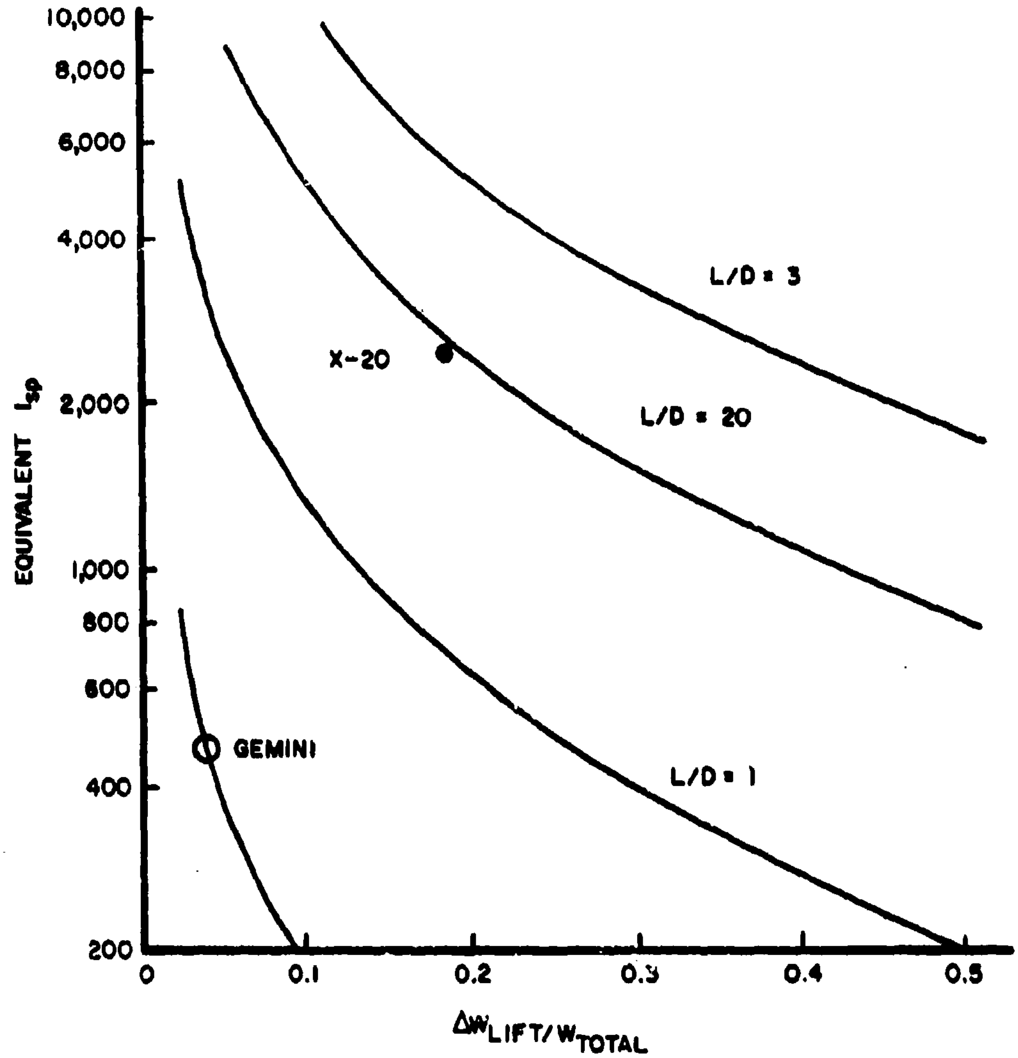

Figure 1. Equivalent I_{sp} of Lifting Surfaces for Lateral Maneuvering

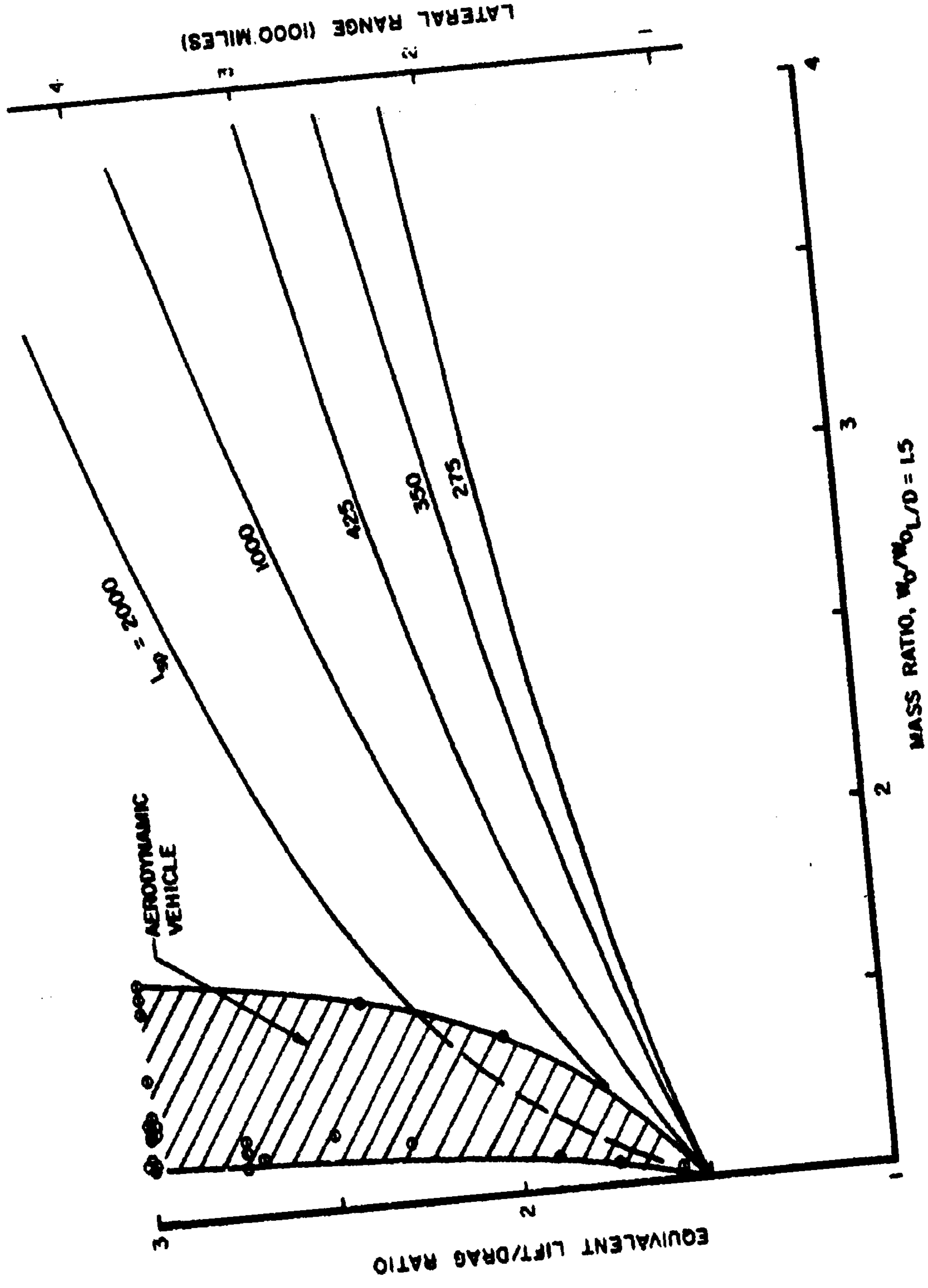

Figure 2. Aerodynamic and Propulsive Trade-Offs for Equivalent L/D

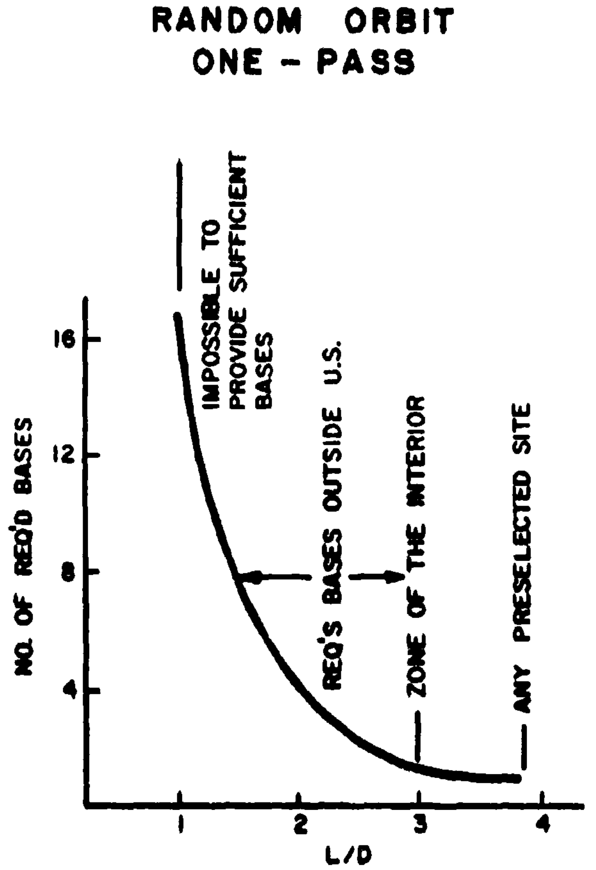

Figure 3. Site Requirements vs Hypersonic L/D

PERFORMANCE FLEXIBILITY

It is truly valid to ask, how many entry spacecraft programs of limited scope can we or should we pursue? It seems undesirable to limit the capabilities of a new system unless this is unavoidable. Flexibility we feel is perhaps the most vital factor in any new spacecraft configuration. Flexibility should be required not only in the available entry corridor and lateral excursions but also in the operational mode and modulation potential. Our past experience should teach us that the cost of initial hardware acquisition is so high that it is only sensible to configure a system having more than limited objectives and which can satisfy both near and far term operational objectives.

This flexibility can be assured through the use of both lift and drag modulation. Operating the vehicle at high angle of attack, it can be seen from Figure 5 that the L/D_{max} achievable at maximum lift coefficient is approximately the same for the medium and high L/D vehicles. The figure shows that the usable range is from 0.6 to 1.0 for the medium L/D vehicle and from 0.6 to 3.0 for the higher L/D configurations. This is further amplified when we consider

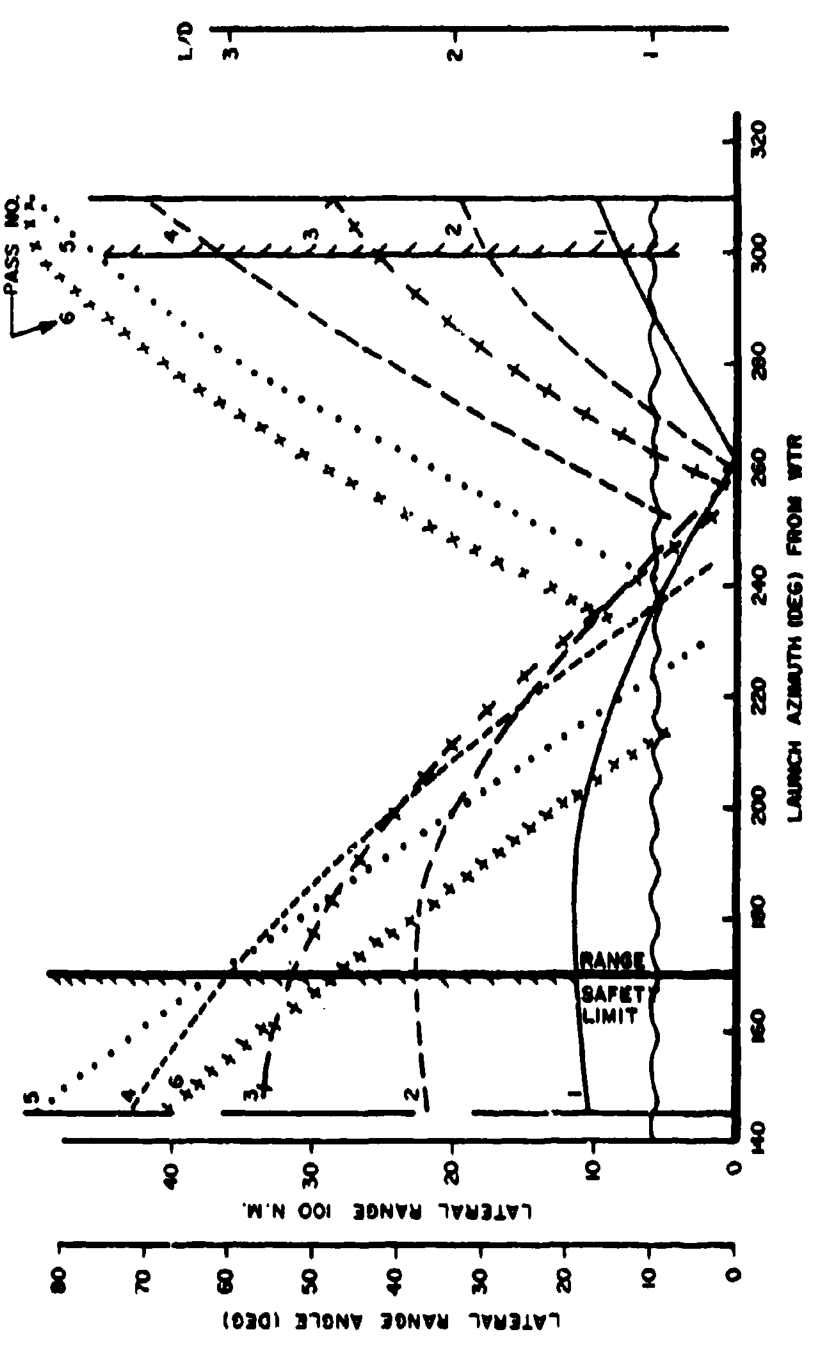

Figure 4. Lateral Range Requirements for Return to Edwards AFB

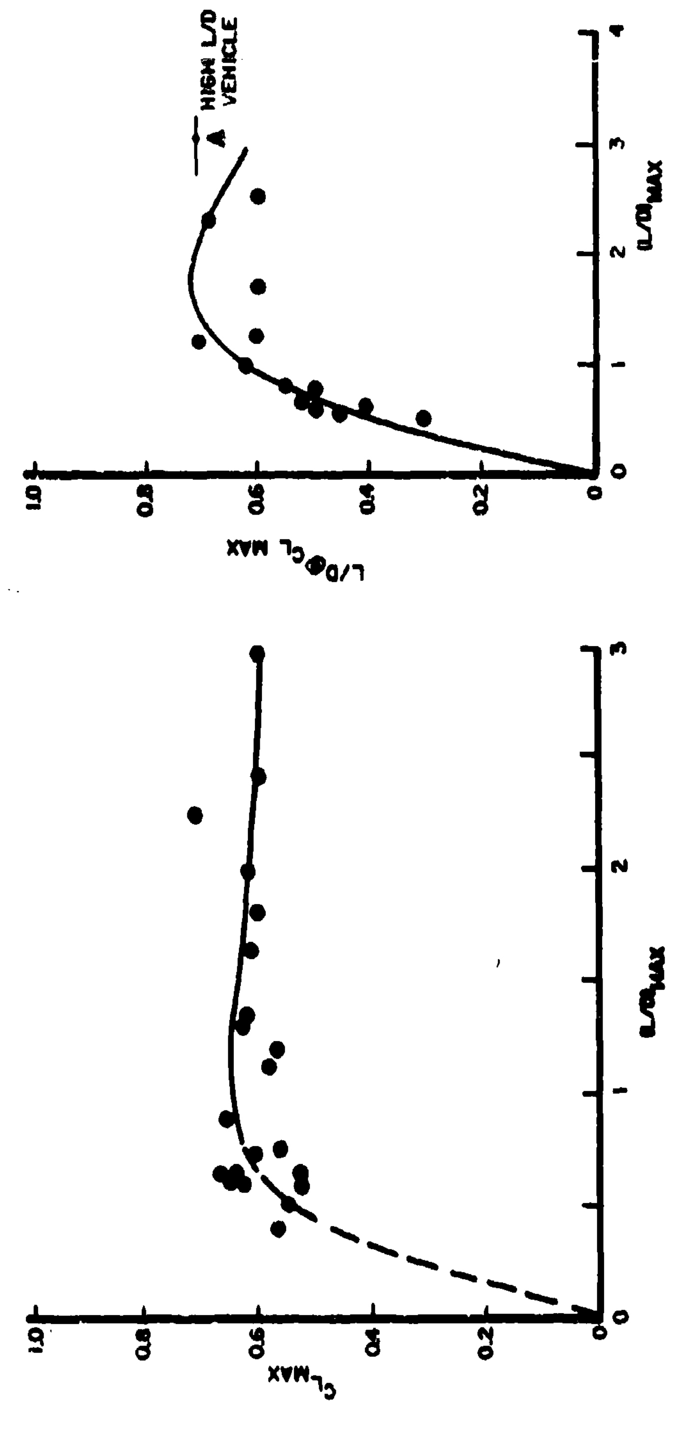

Figure 5. Variation of $C_{L_{max}}$ and $\frac{L}{D}@C_{L_{max}}$ vs L/D_{max}

the actual value of the maximum lift coefficient. Figure 5 also indicates that the maximum available lift coefficient is relatively insensitive to design L/D in excess of 0.5. Figure 6 indicates the effect of both lift and drag modulation on the flight duration as well as past and present flight programs in the area, while Figure 7 shows the effect of design L/D on the maximum and minimum entry times for $\gamma \approx 0°$.

Another feature associated with flexibility is the maneuverability potential inherent in any vehicle design. Again, this is directly related to the L/D and the selected design point in terms of altitude and velocity. The desirability for lateral range may reflect itself in such ways as reduction in orbital delay, minimum landing sites, area coverage, improved abort capability, etc. We have previously indicated the advantages relative to landing site requirement in Figure 3 which was based on a nonrestrictive location and orientation at the decision point.

Another rather useful way of comparing the maneuvering capability of various vehicles is through the payload delivery index η_{GL}; (Reference 4) as shown in Figure 8. This parameter couples the packaging and performance potential (fraction of the earth's surface available for exploitation from a given set of initial conditions) and is expressed simply as:

$$\eta_{GL} = \frac{V^{2/3}}{S_{wet}} \quad \frac{S_{footprint}}{S_{earth}}$$

BOOSTER ASSESSMENT

Considerable discussion has centered around the weight of different classes of entry vehicles. We certainly recognize the necessity of minimizing any penalties associated with payload considerations. Any discussion, however, must include improved operational characteristics and not limit itself simply to the minimum weight system. Operational potential may, in fact, be the most important consideration for as previously noted the ballistic vehicles maximize effectively the payload fraction. Another factor most important in determining the question of system weight is the current and projected launch vehicle capability. Figure 9 gives a general indication of launch vehicle capability with entry vehicle weight. In the case of Mercury/Atlas and Gemini/Titan, the entry vehicle weight had to be minimized for in both instances the complete spacecraft system very closely approached the limiting capability of the launch systems. Such is no longer the case, however, with launch systems in the Titan III and Saturn classes. In fact, the reverse may very well be the case in that embarrassingly small payloads are often considered for these launch systems which in no way taxes their capability. It can be seen from this figure that considerable margins exist above the entry vehicle weights which are available for adapter modules, payloads and maneuver propulsion. This coupled with the realization that the launch vehicle's capability compared to the entry vehicle's capability is relatively easy to up-rate makes the entire question of entry vehicle weight less critical than that which we faced in our early activities. With the margins now available in terms of weight for our launch systems it would appear quite prudent to invest in increased performance versatility.

COMMONALITY OF TECHNOLOGY

As we have previously suggested, any new spacecraft concept must have a significantly improved operational capability along with multiconcept applicability of the technology. The technology demanded by the high L/D vehicle during orbital lifting reentry has much in common with that which is required both for hypersonic sustained cruise and recoverable booster concepts. In spite of the superficial differences in applications and concepts, a commonality of problem areas and similarity of configuration elements and flight attitudes is readily apparent.

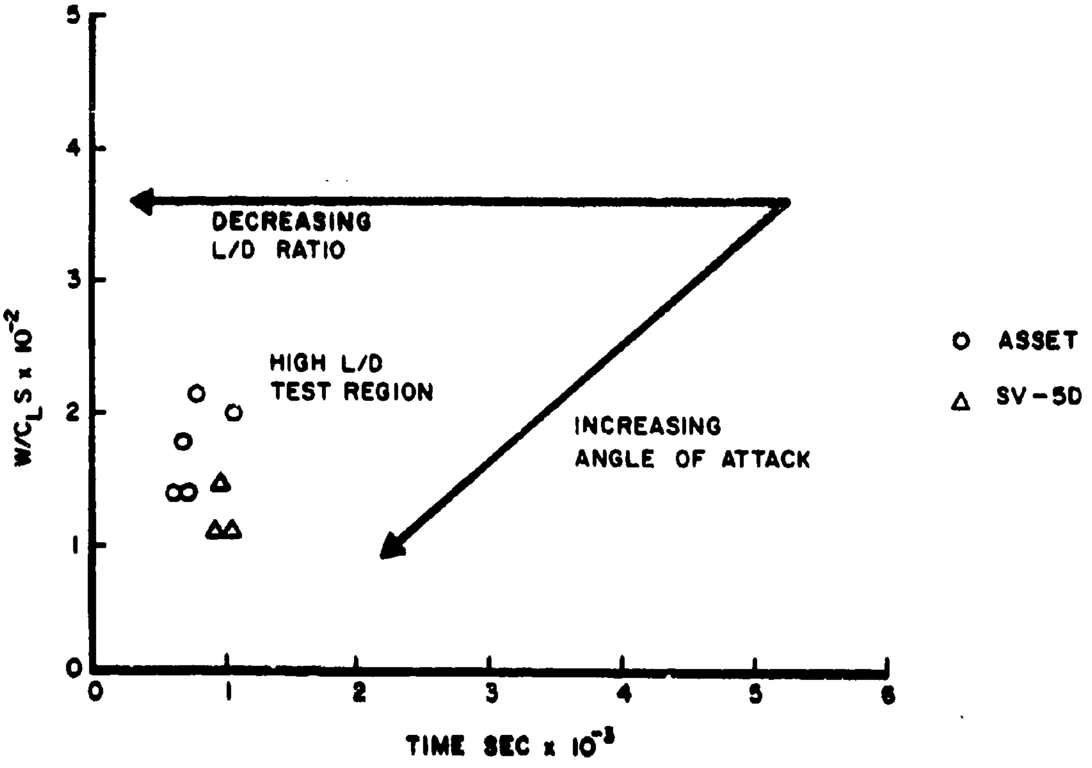

Figure 6. Effect of Lift and Drag Modulation on Reentry Time

These concepts of the high L/D spacecraft, hypersonic cruise vehicles, and recoverable boosters suggest the need for high aerodynamic efficiency. Since reduced nose and leading edge radii are common features, the complete viscous problem of skin friction levels, viscous interaction, and boundary layer transition are of significant importance. In all cases, turbulent heating is of consequence and is size dependent.

All the vehicles operate at reduced angles for C_L optimum and in the case of entry and cruise vehicles have relatively long exposure times in the high temperature environment, thereby suggesting application of refractory and superalloy radiative material for large portions of the vehicle. The attendant problems of refractory coatings and reusability are certainly paramount and common technology requirements. Again, because of the flight durations involved, the likelihood of aerodynamic control surfaces for each of the concepts is high, thereby bringing into focus many problems associated with control surface effectiveness and heating.

It is important, however, to tie the concept of flexibility and applicability together with the realization that the high L/D vehicle need not perform in its highly efficient mode at all times. Many problems more closely associated with the lower performance systems such as the behavior of various ablators can be quite properly addressed with the high L/D vehicle. Suffice it to say, that the high L/D can perform as a lower L/D vehicle where the latter

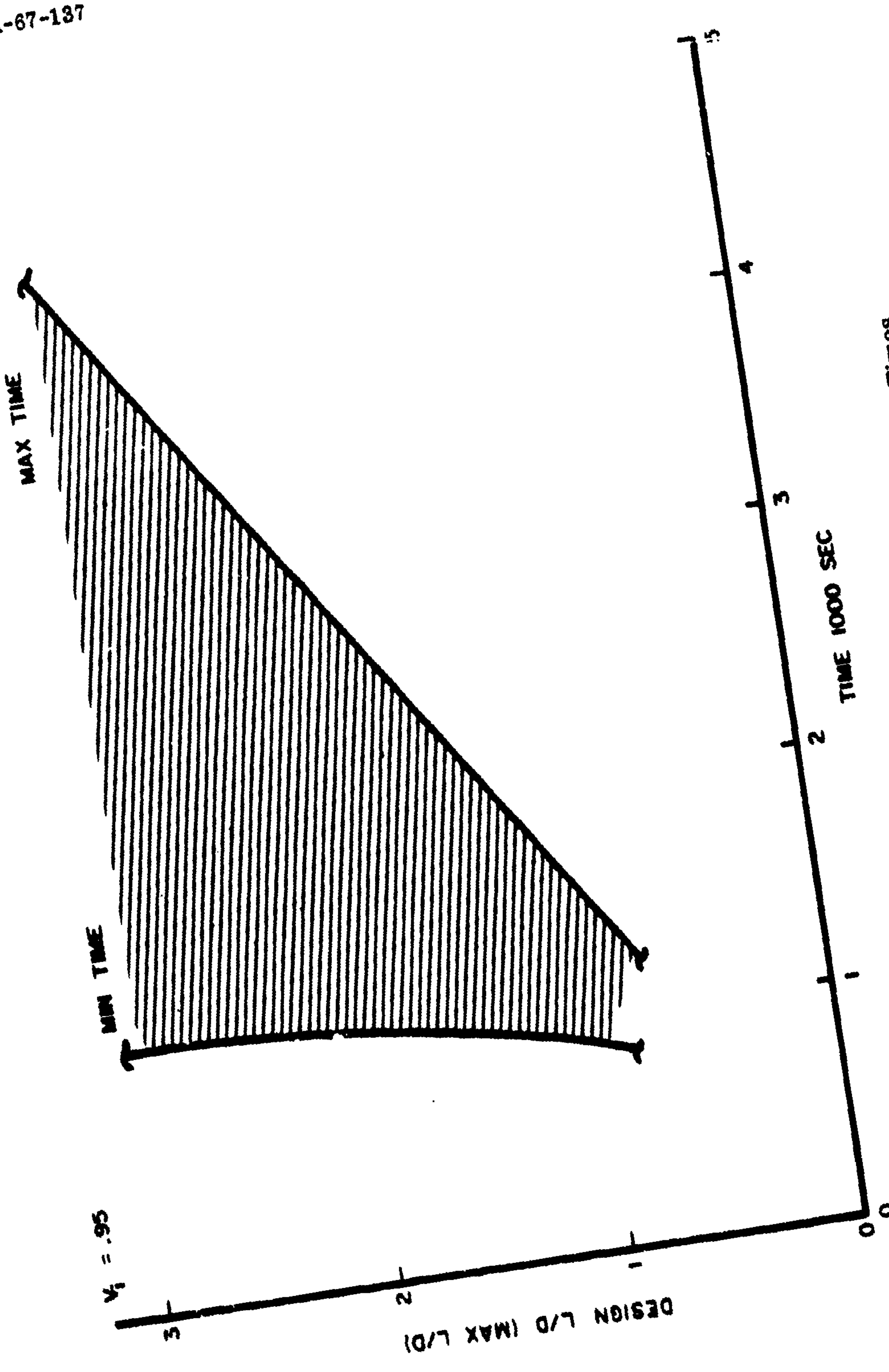

Figure 7. Effect of Design L/D on Possible Flight Times

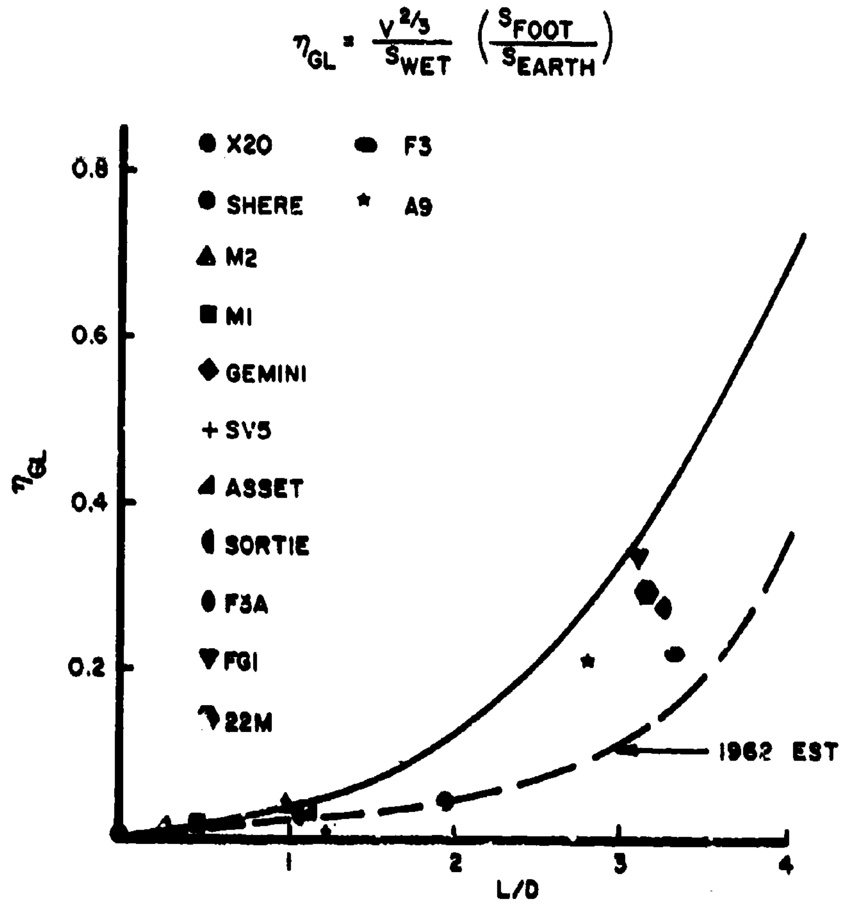

Figure 8. Payload Delivery Index vs Hypersonic L/D

cannot function as a high performance system without the use of on-board propulsion which we will discuss later.

The acquisition of technology as a goal through flight testing is not new or novel as characterized by the "X" series of experimental aircraft. In fact, flight testing has been an integral part of the progress in technology demonstration leading to the definition and development of new systems and systems concepts. While exploratory development probes problem areas generally in the separate technologies and while mission studies tend to direct attention to potential system candidates, the role of flight testing is pivotal since it integrates and demonstrates the separate technologies and provides the mission analyst with a firm basis of comparison for the selection of future systems.

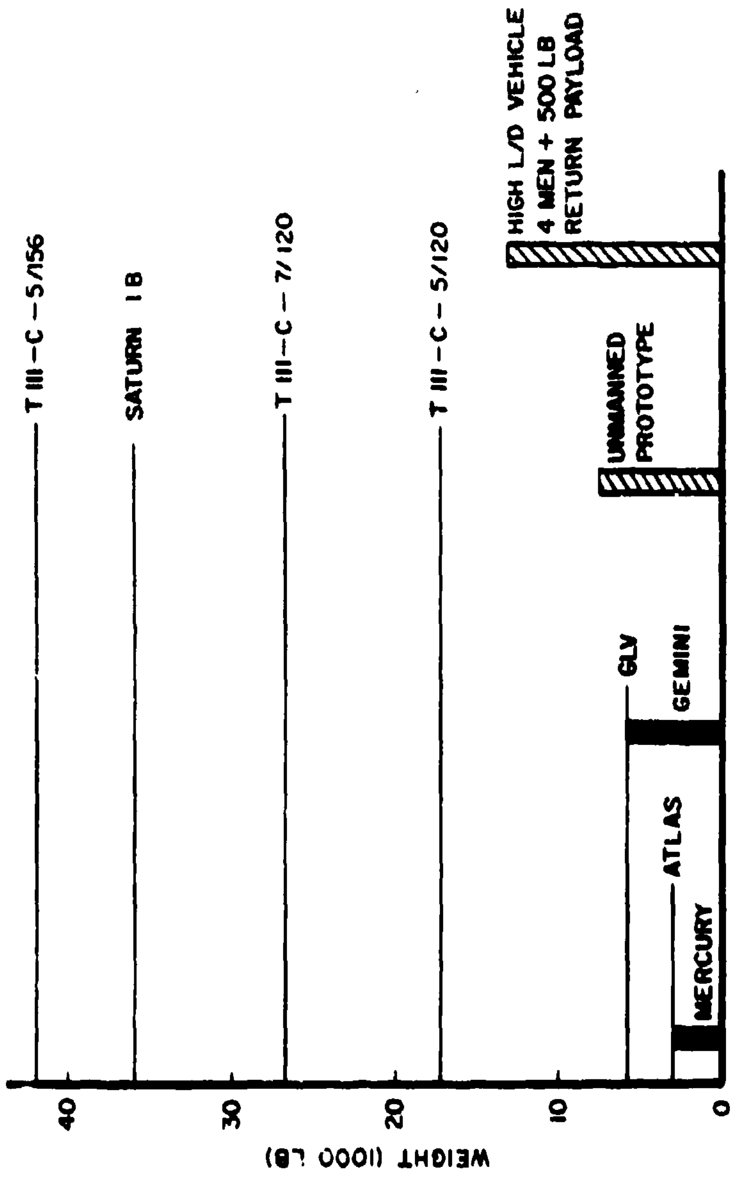

Figure 9. Launch Vehicle Capability

SECTION III

CONFIGURATION DEVELOPMENT

In 1963 the investigation of the high L/D vehicular concept was initiated in earnest. At that time there existed a number of questions to be answered, many of which have now been answered in a rapidly expanding technology. The following comments will discuss these considerations:

The feasibility of high hypersonic L/D: The Air Force Flight Dynamics Laboratory defined high hypersonic L/D as an L/D = 3.0 at an altitude of 200,000 feet and a velocity of 20,000 ft/sec. This design point was selected to encompass the high velocity regime at an altitude where viscous forces are significant. The first attempts were to demonstrate in ground facilities that an L/D = 3.0 could be obtained. Figure 10 shows the results of initial tests at AEDC (References 5 and 6). For the sharp nose, it was apparent that an L/D = 3.0 was indeed possible but for the blunt nose an L/D = 3.0 could not be achieved. After this initial attempt a program using more realism was conducted. The results from this effort are shown in Figure 11. The configurations were moderately simple geometric shapes, but they incorporated volume, bluntness and aerodynamic control surfaces. Using a form of the viscous interaction parameter for extrapolating the data it was apparent that several of the configurations would achieve an L/D = 3.0 at the design condition. So at least in ground facilities, the feasibility had been established.

The next question which grew out of this earlier work was whether high L/D could be achieved with configurations which possessed adequate usable volume. This has been a difficult question to answer since it depends so much on what use will be made of the volume (packing density). Our approach has been to examine the geometric variables and their influence on L/D and attempt to shape the vehicle to perform trades between L/D, volume, and vehicle length. This has been both an analytical and experimental program; the results shown in Figure 12 give an example of the volume growth in this concept. From this figure we can see that the load carrying capability of the vehicle is increasing as we become more knowledgeable about the trade-offs. The vehicles are shown for a length of 33 feet. From this analysis we conclude that in most instances adequate volume can be obtained with moderate vehicle lengths still maintaining our goal of an L/D of 3.0.

The next question plagues every system and is simply: whether the vehicle can be made competitive from a weight standpoint? This question is settled only after the vehicle is fabricated. Yet attempts must be made for reasonable estimates of the weight for comparative purposes. There exists a number of spacecraft for which comparisons can be made. In the area of the lifting reentry vehicle background information is available in the hard design points of the ASSET, X-20 and PRIME. But in the case of the ASSET and X-20, we must recognize the technological advances which have been made in the past few years as well as the conservatism employed in these designs. To provide some insight, the weight question has been examined in a number of comprehensive design studies and the results are shown in Figure 13. There exists a trade-off between vehicle weight and L/D, but the decision must be made on the basis of what gains can be obtained for relatively small penalties. In this instance, as shown in Figure 13 the weight penalties are comparatively minor when viewed in terms of the increased performance potential and versatility.

The final question concerns the thermal environment and its constraints on the vehicle. The constraints are imposed by material limitations and increased heating when maneuvering the vehicle. Figure 14 shows the relationship between angle of attack and bank angle for various wing loads based on a temperature constraint near the leading edge on the lower surface (Reference 7). From the figure it is apparent that the ability of the vehicle to transverse

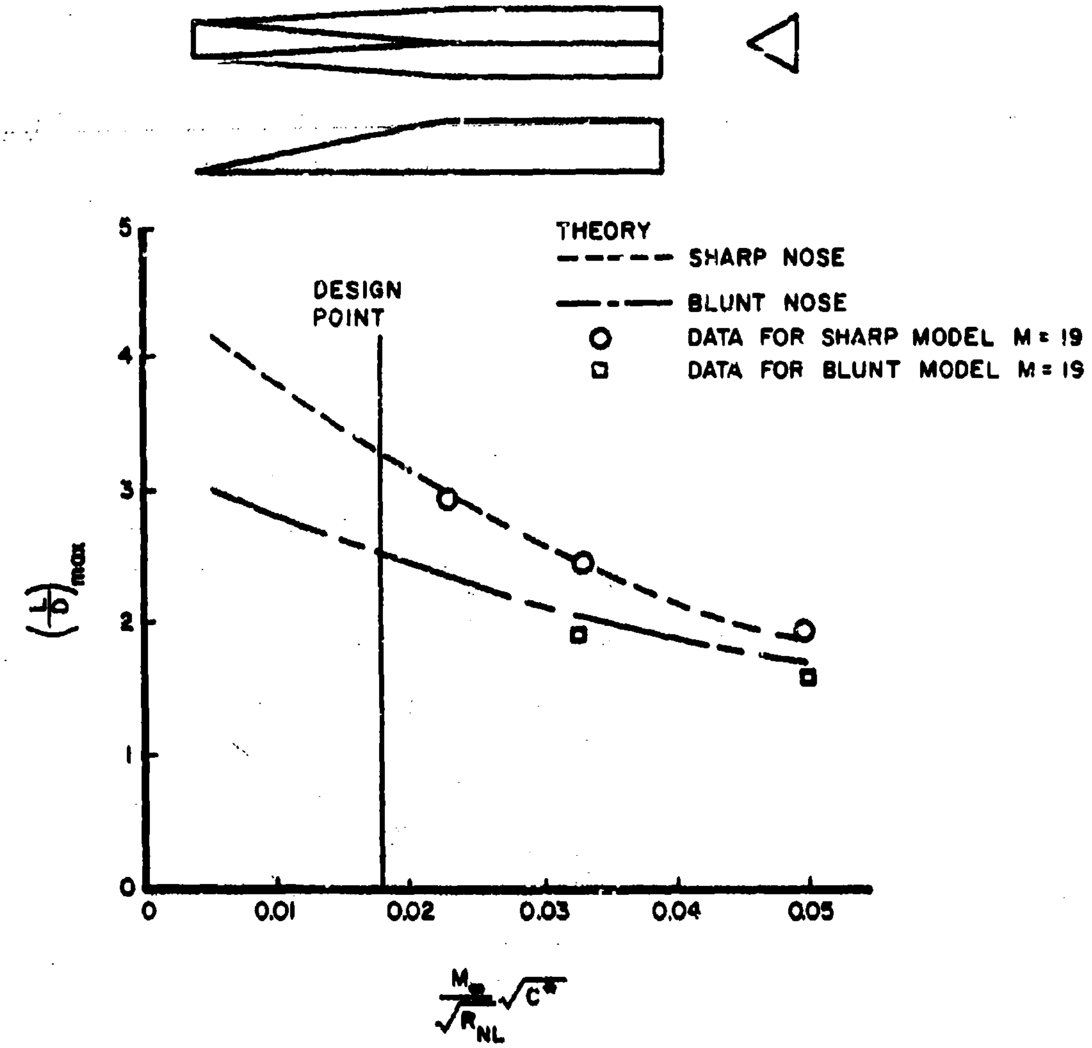

Figure 10. Variation of L/D_{max} with Rarefaction Parameter

significant bank angles and angles of attack is not seriously impaired. The usual problems of high heating exist but are not beyond the technology. For example, comparable nose caps, successfully used on the ASSET can likely be employed; the leading edge radii would again be similar to the ASSET both in size and temperature level.

The high L/D vehicle configurations have progressed to the point where a stable vehicle with a high volume and high L/D can be designed which is controllable and can sustain the heating environment.

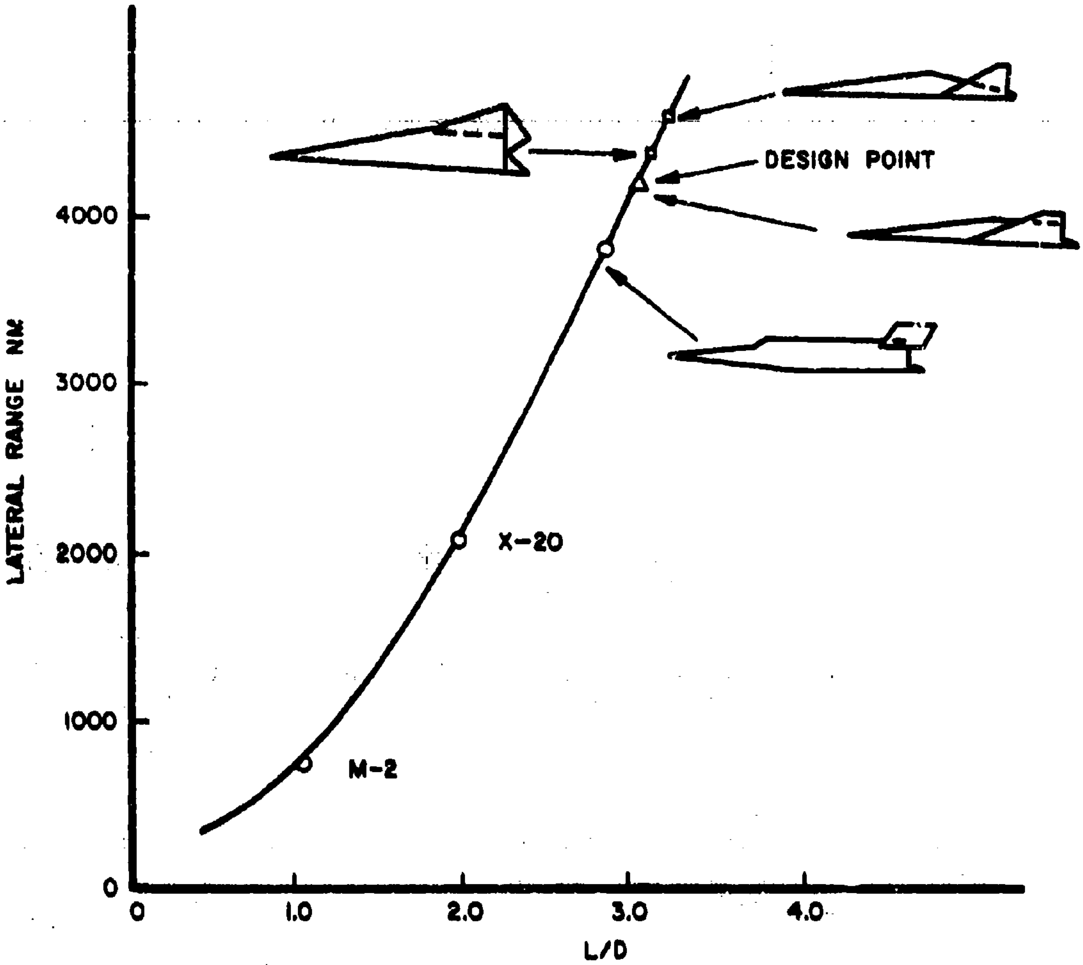

Figure 11. L/D Achieved vs Design Point; Effect on Lateral Range

POTENTIAL CONFIGURATIONS

Based upon the investigations made to date, Figure 15 gives a pictorial representation of configurations which have led to the candidate vehicles being comprehensively examined at this time. Additional criteria have been imposed on the designs to incorporate satisfactory characteristics for low speed flight employing both fixed and variable geometry.

INCORPORATION OF MAN AND PROPULSION

We have indicated that the high L/D vehicle is not at all incompatible with volume requirements and it should be emphasized that volume rather than volumetric efficiency, $V^{2/3}/S_w$, is of importance in final vehicle design, since it is volume which must be provided for any payload requirements. Volumetric efficiency, at best, is only an indicator when parametric

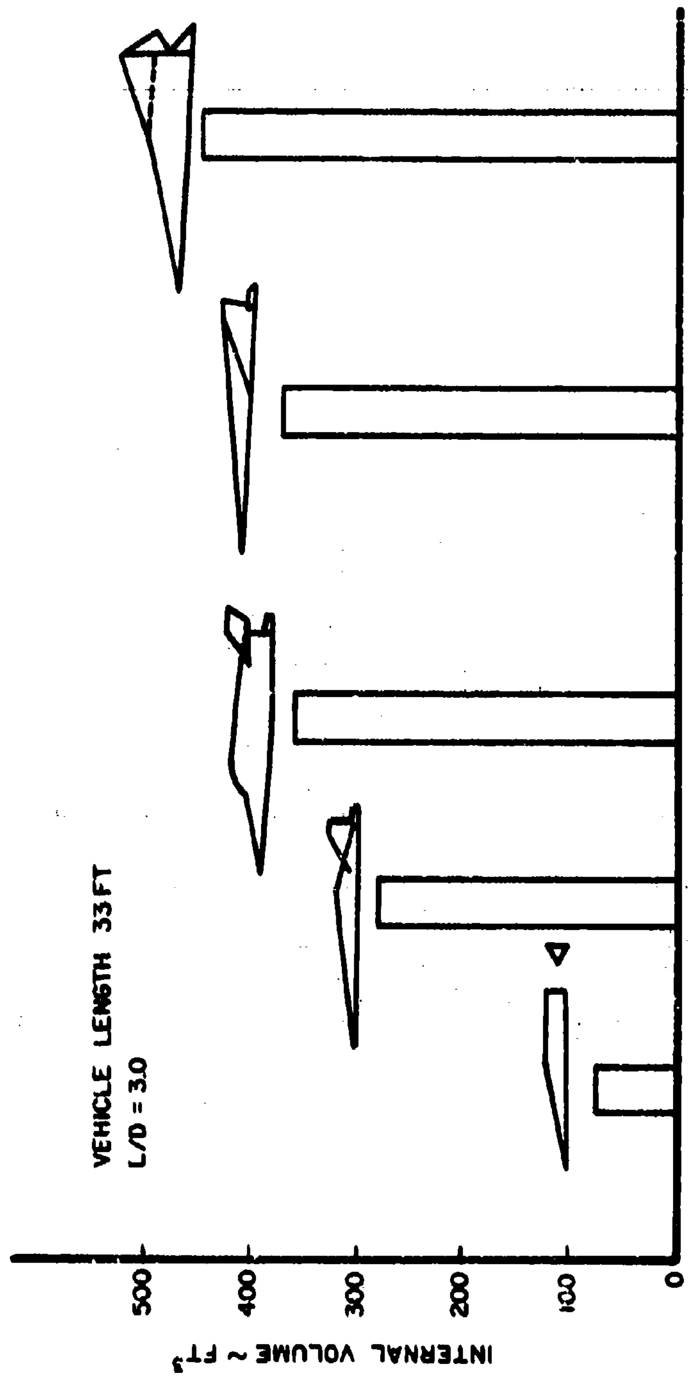

Figure 12. Volume Variation with Vehicle Evolution

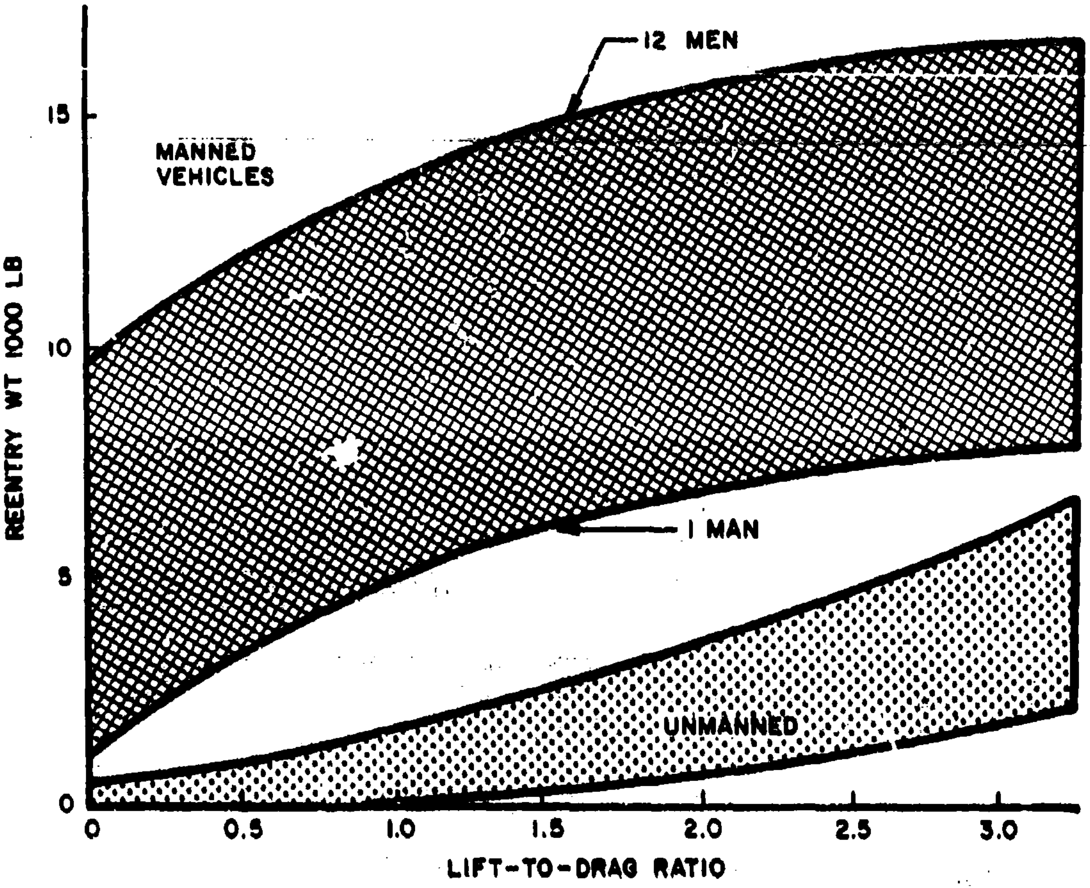

Figure 13. Vehicle Weight for Reentry Systems

comparisons are being made and is of much less significance as vehicle sizes increase compatible with manned and on-board propulsion applications.

It is important to recognize that the high L/D vehicle must be in the order of 30 feet long to achieve the desired aerodynamic efficiency, hence they possess the size and volume requirements for manned applications. The lower performance design, L/D 1.0, can be realized with smaller sizes but must eventually experience a more substantial growth rate to achieve the sizes and volumes for manned applications. Figure 16 gives an indication of the size requirements for such vehicles.

Wing loading is also of consequence in the design of any system from its impact on the thermal protection system. If a complete reradiative thermal protection system is desirable, then wing loadings must be regulated to assure temperatures compatible with the limit temperatures of the materials employed and normally result in wing loadings of approximately 40. To give some indication that these values are not completely rigid it is only necessary to look at where the limiting temperatures are achieved. These generally occur at the shoulder near

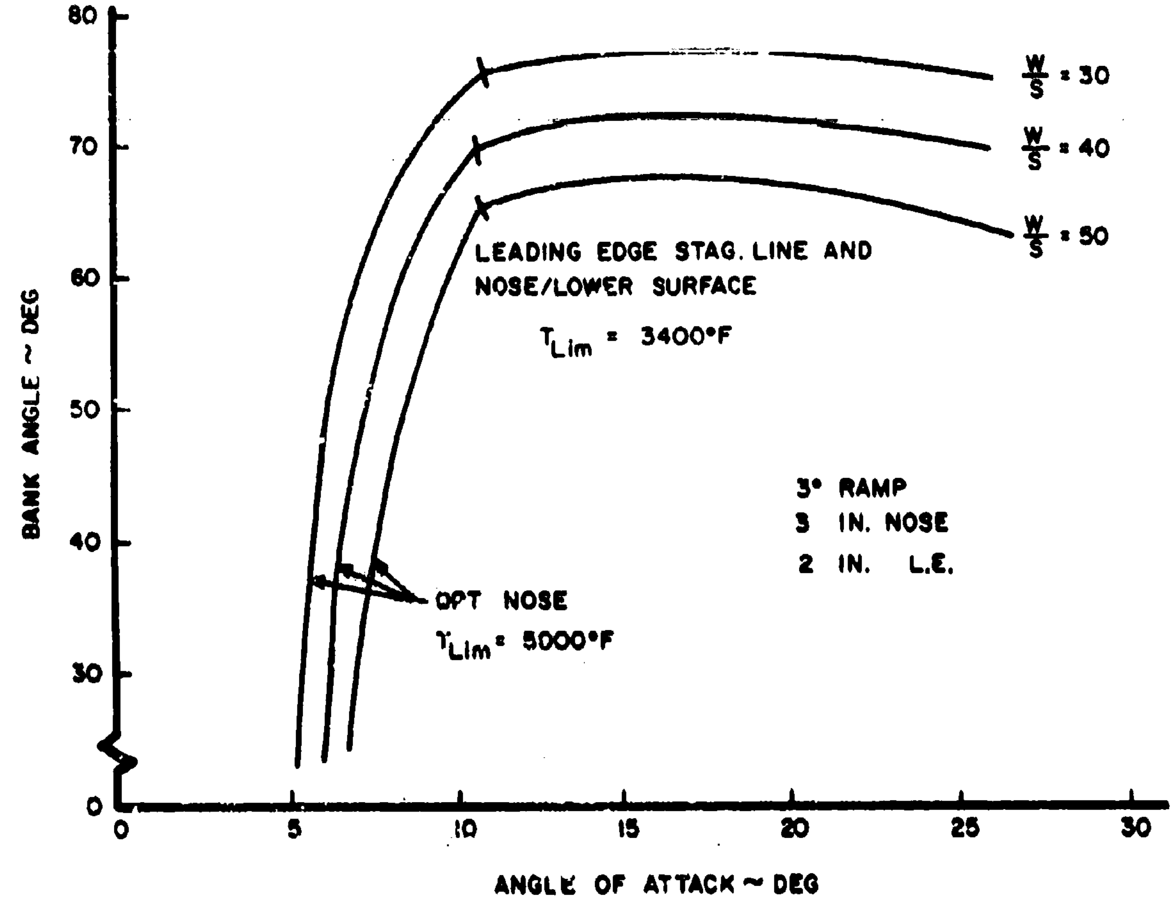

Figure 14. Temperature Constraints on Vehicle Attitude

the leading edge and W/S can be increased by extending the refractory metals aft where the temperatures are compatible with the prime material planned for use.

The wing loadings which are normally cited should be considered as "anchor" or "base points" which allow full maneuvering and performance excursions during return without exceeding the temperature capabilities of refractories. These values, however, should not be considered as absolute limits for mission or vehicle usage in view of the following reasons.

For designs which employ integral propulsion, there exist no reason to restrict the W/S to the "anchor" values for, indeed, values as high as 100 have been investigated and proven feasible if the vehicle is operated in the aerocruise mode. The aerocruise mode simply couples the maneuver at constrained temperatures to the maximum allowable for the materials by either maintaining velocity, altitude or both. This concept can be oversimplified by

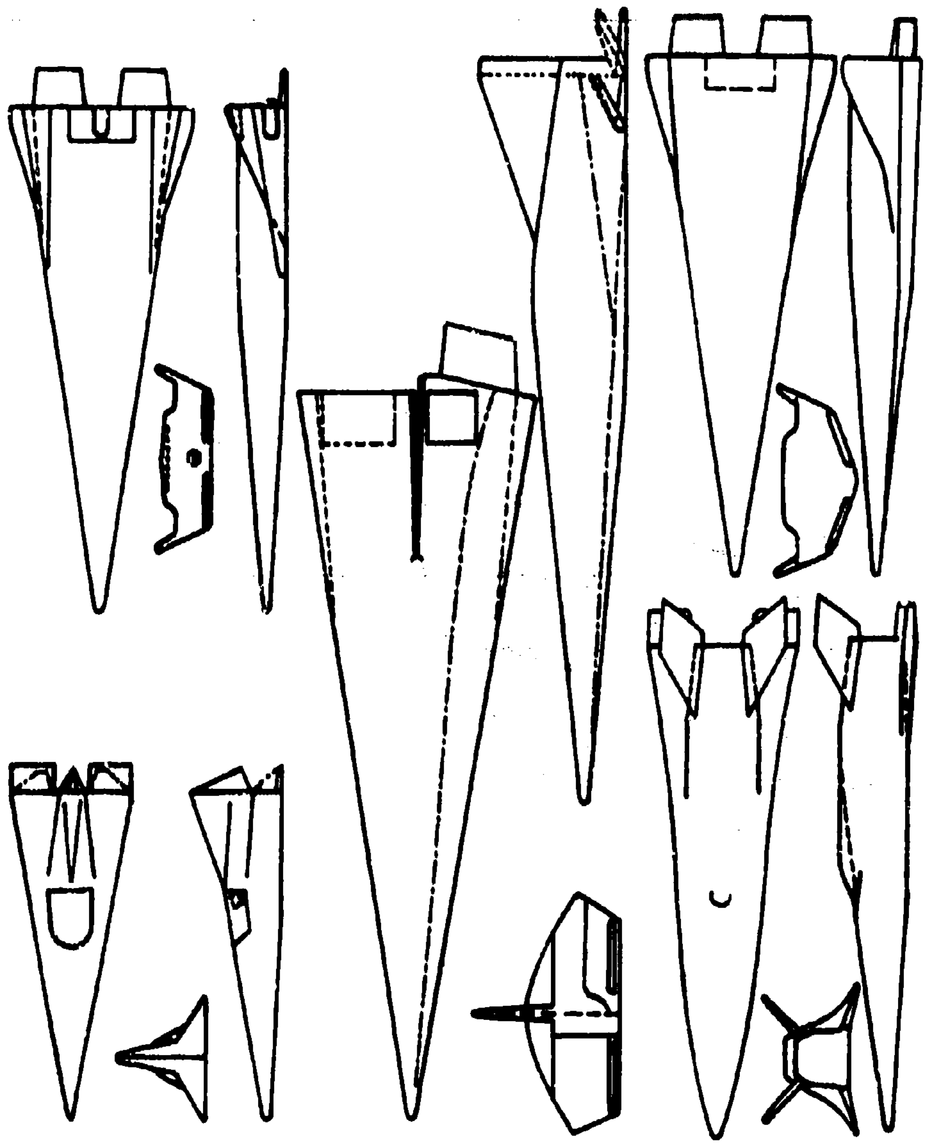

Figure 15. High L/D Configuration Concepts

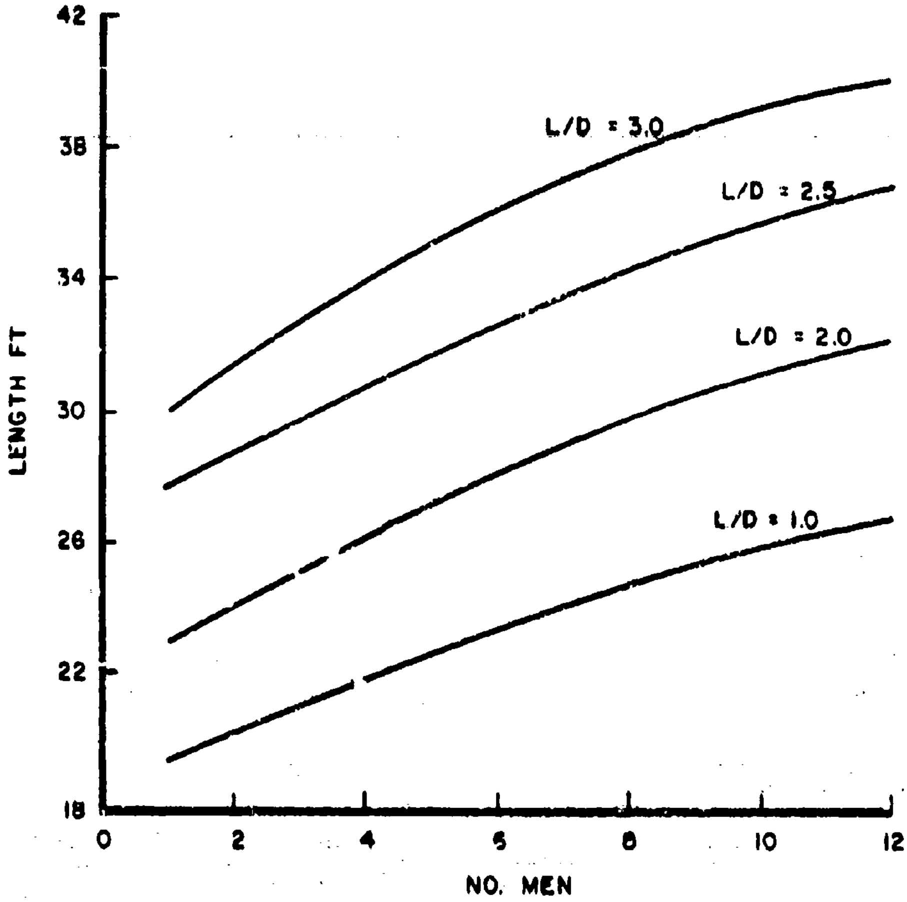

Figure 16. Effect of Number of Men on Vehicle Length

consideration of several factors. Rocket propulsive devices, by their very nature, prefer the operating environment of space or at least at low atmospheric densities. The use of aerodynamic maneuvering, on the other hand, suggests lower altitudes to take advantage of the lifting capability. These two methods can be combined to enable a highly efficient vehicle which can operate within allowable temperature constraints. If the maneuvering is accomplished with a vehicle with integrated propulsion, the "anchor" wing loadings are then the applicable values for the empty vehicle. If some fuel still remains resulting in wing loading in excess of the "anchor" values, then two alternatives are available. The fuel may be jettisoned as in the case of current aircraft, or maneuvering during final entry may be programmed or constrained within the limits of the resulting wing loadings which may not offer any serious degradation in maneuvering capability. Again, however, if the values are maintained at those given as "anchor" points for both the powered and unpowered cases, full reentry maneuvering would be available and could be combined with that achieved during the aerocruise mode of operation.

If hybrid thermal protection is employed such as a combination of refractories and low density ablators, then it follows quite logically that the "anchor" wing loadings can be increased significantly. Recent investigations have shown that W/S = 65 can be sustained with unpowered high L/D vehicles (Reference 8). The implications associated with resulting increased return payload weights are quite obvious.

SECTION IV

CONCLUDING REMARKS

The low L/D technology as exemplified by the Mercury, Gemini, and Apollo programs necessitates that any advantages associated with any new lifting entry concept must be clearly defined and significantly measurable. The environment also appears to be one in which there exists no clearly defined advanced missions, explicit applications, or precisely delineated requirements. With these thoughts in mind, it would appear that perhaps the most probable avenue to a new vehicle capability would be through the technology mechanism. The necessity for technology verification of alternate candidate concepts may indeed be the sensible approach, for this preserves the options and presents realistic alternatives to the decision makers when plausible applications become more clearly in focus.

The question as to whether new vehicle concepts should be manned or unmanned is not easily answered and must be viewed carefully considering such constraints as the type of information desired and potential cost escalations. At this point in time, it appears that hypersonic exploitation and demonstration would be initially accomplished on an unmanned basis in that significant technology acquisition can be affected without experiencing the cost increases associated with man-rated systems.

In summary, we would agree that much has indeed been written on entry vehicles, we can anticipate much more and can expect to profit from additional commentaries. We would further submit that in view of the currently successful low L/D technology and the lack of precisely defined advanced applications that an appropriate parameter for comparison is L/D and the motivation most likely ought to be technology with increased performance potential.

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13. ABSTRACT

Many investigations related to hypersonic flight and return from orbit have been conducted and from the results of these studies design concepts have been evolved across the complete lift-to-drag ratio spectrum for entry. By way of introduction, this report considers the relationship between any new lifting entry vehicle and the established low L/D or ballistic spacecraft technology. It is shown that a substantial base of knowledge exists from the successful flights of the ASSET and SV-5D along with the technology obtained from the X-20 program. To place lifting vehicles in their proper perspective a review of some of the advantages traditionally associated with the generation of lift is given, and a realistic view is taken of some of the maneuvering constraints which can be required. Particular emphasis is placed on the performance flexibility which can be achieved. Specific technology features common to complementary advanced systems are identified and assessed relative to launch vehicle constraints. Finally, the evolution of highly efficient lifting bodies is traced. Potential configurations for reentry are delineated, these configurations are assessed in relation to their heating, volume, and weight. The incorporation of man and on-board propulsion is shown to be completely compatible and advantageous with the candidate high lift-to-drag ratio configurations. In conclusion the lack of well defined mission requirements indicates the advisability of preserving the options available. Hence, operating potential can best be realized by maintaining high performance flexibility through high hypersonic L/D.

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High L/D						
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ERRATA

AFFDL TR 67-137, Assessment of the Factors Affecting Advanced Lifting Entry Vehicles

Air Force Flight Dynamics Laboratory

Page 4, Figure 1

L/D = 20 should be L/D = 2

Pages 9 and 12

Equation

$$\eta_{GL} = \frac{V^{2/3}}{S_{wet}} \quad \frac{S_{footprint}}{S_{earth}}$$

should read

$$\eta_{GL} = 4.83 \, \frac{V^{2/3}}{S_{wet}} \quad \frac{S_{footprint}}{S_{earth}}$$